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(54) **Reconfigurable frequency selective surfaces**

(57) A reconfigurable frequency selective surface comprises at least two arrays (1, 2) of elements (3), the arrays (1, 2) being arranged in close proximity with one another so that elements (3) of a first array (1) are closely coupled with elements (3) of a second array (2) adjacent to the first array (1). The first array (1) is displaceable with respect to the second array (2) to adjust the frequency response of the surface. The displacement may be of translation or rotation. Reference is also made to varying the refractive index of the separating dielectric medium.

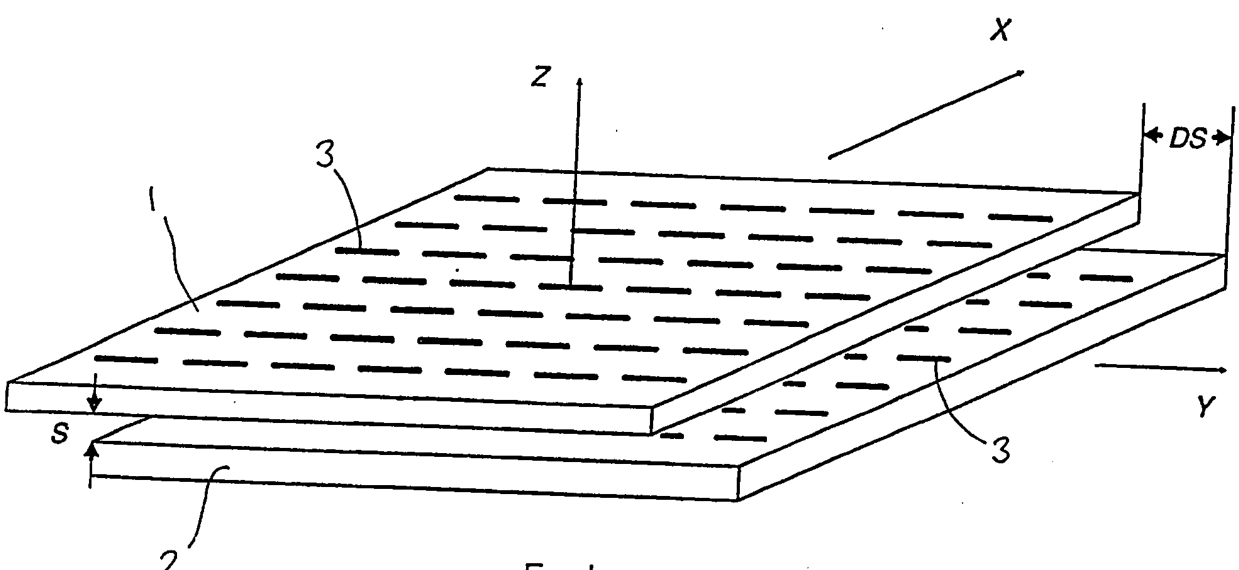

Fig. 1

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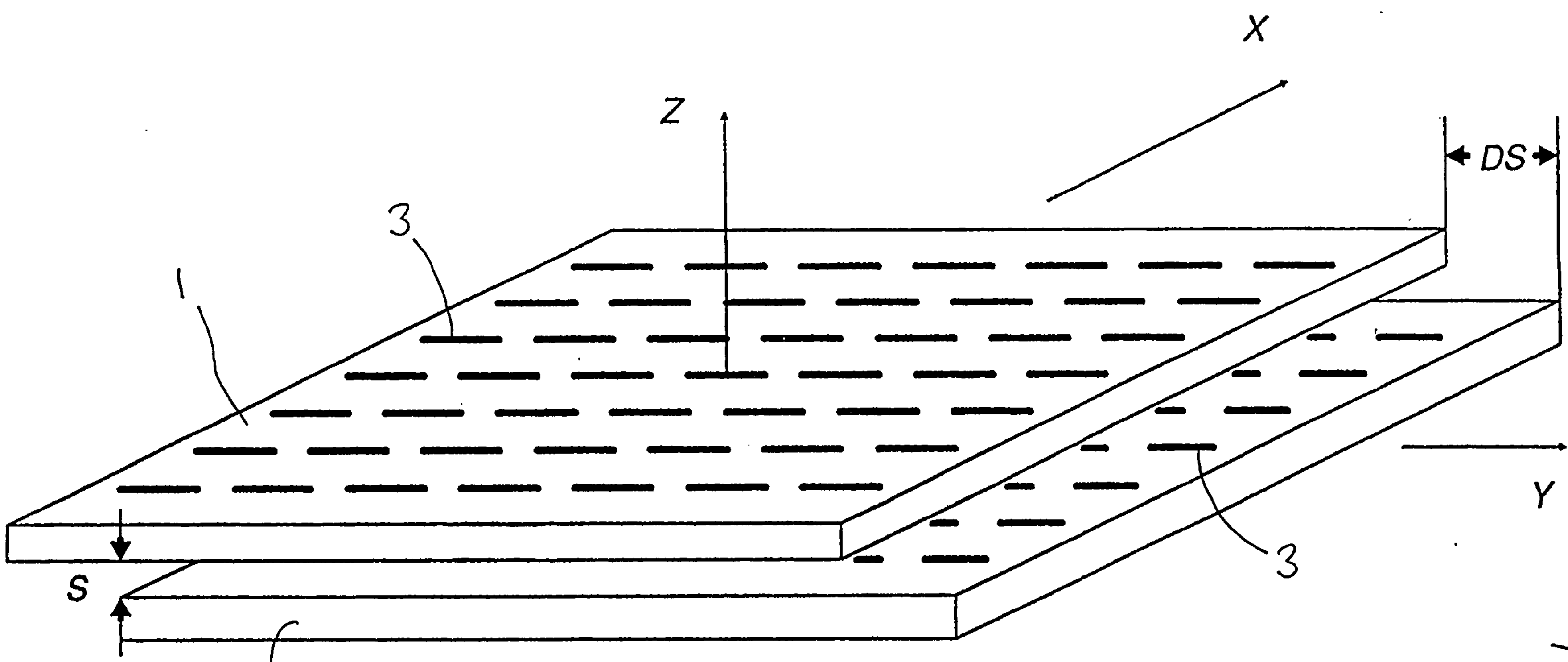


Fig.1

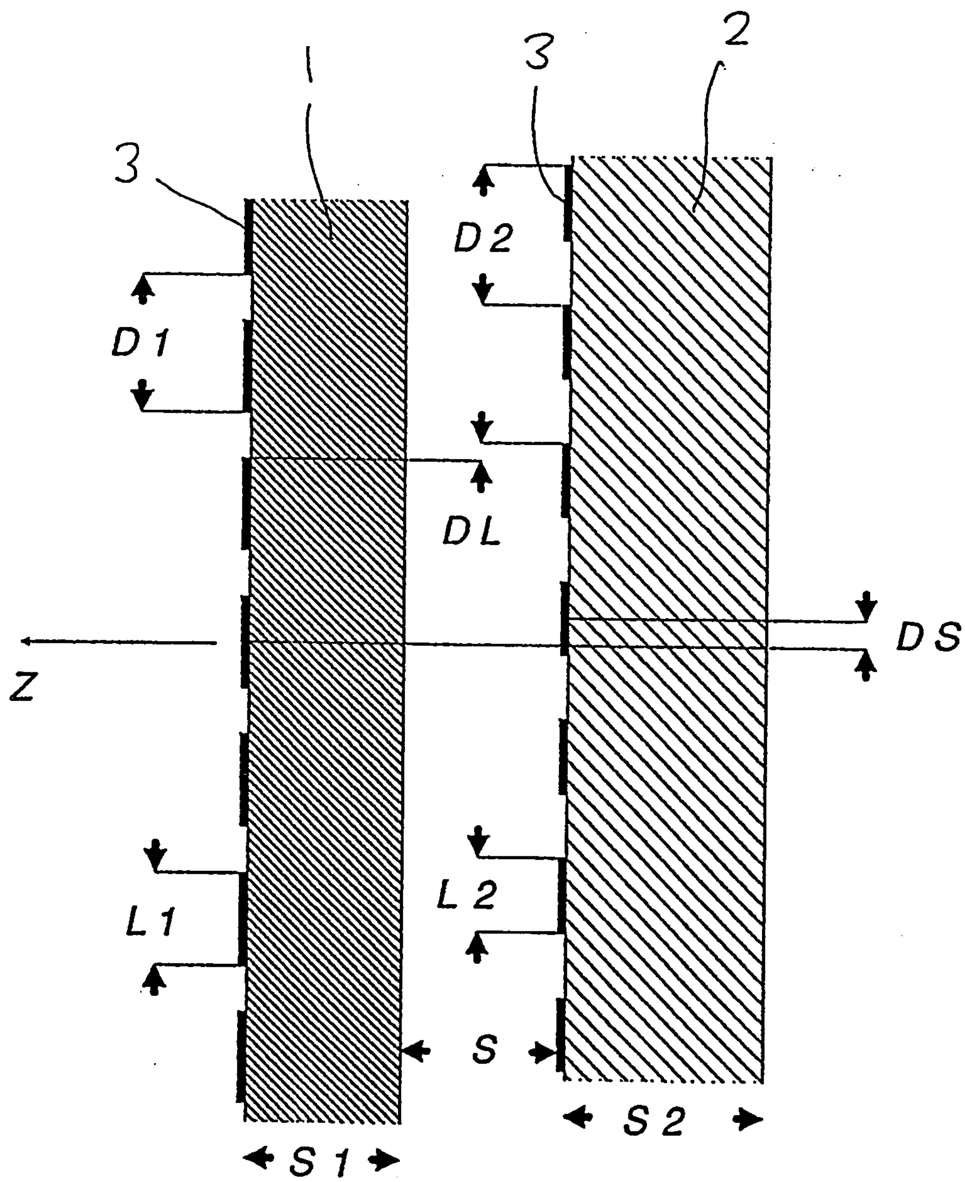


Fig. 2

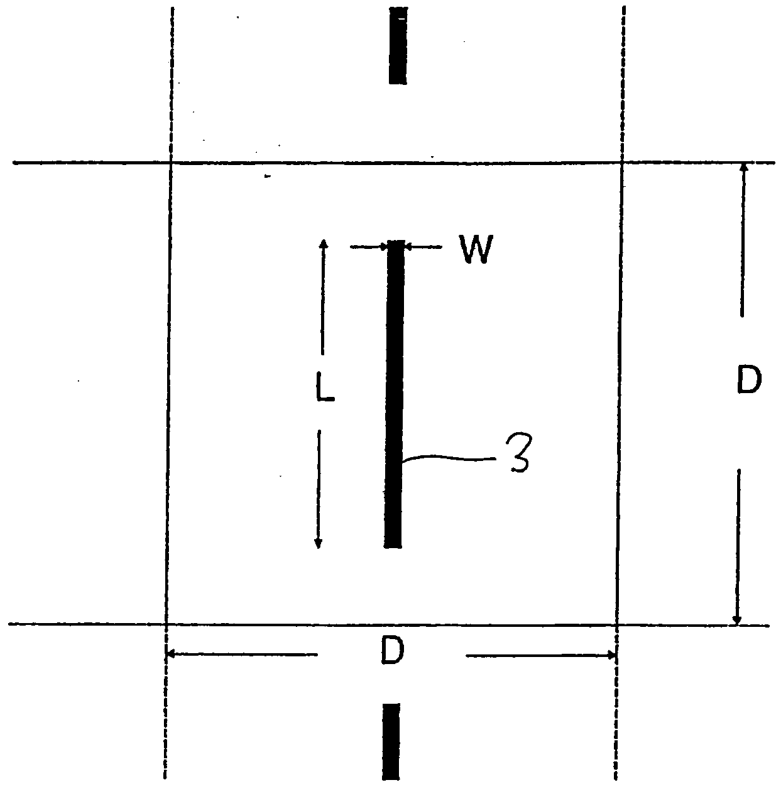


Fig. 3

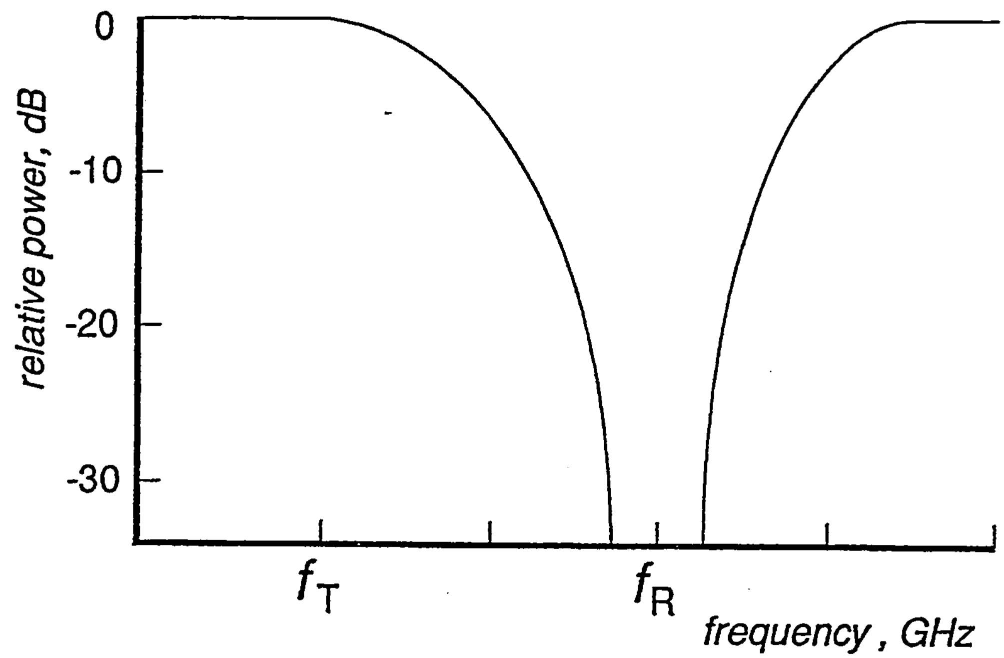
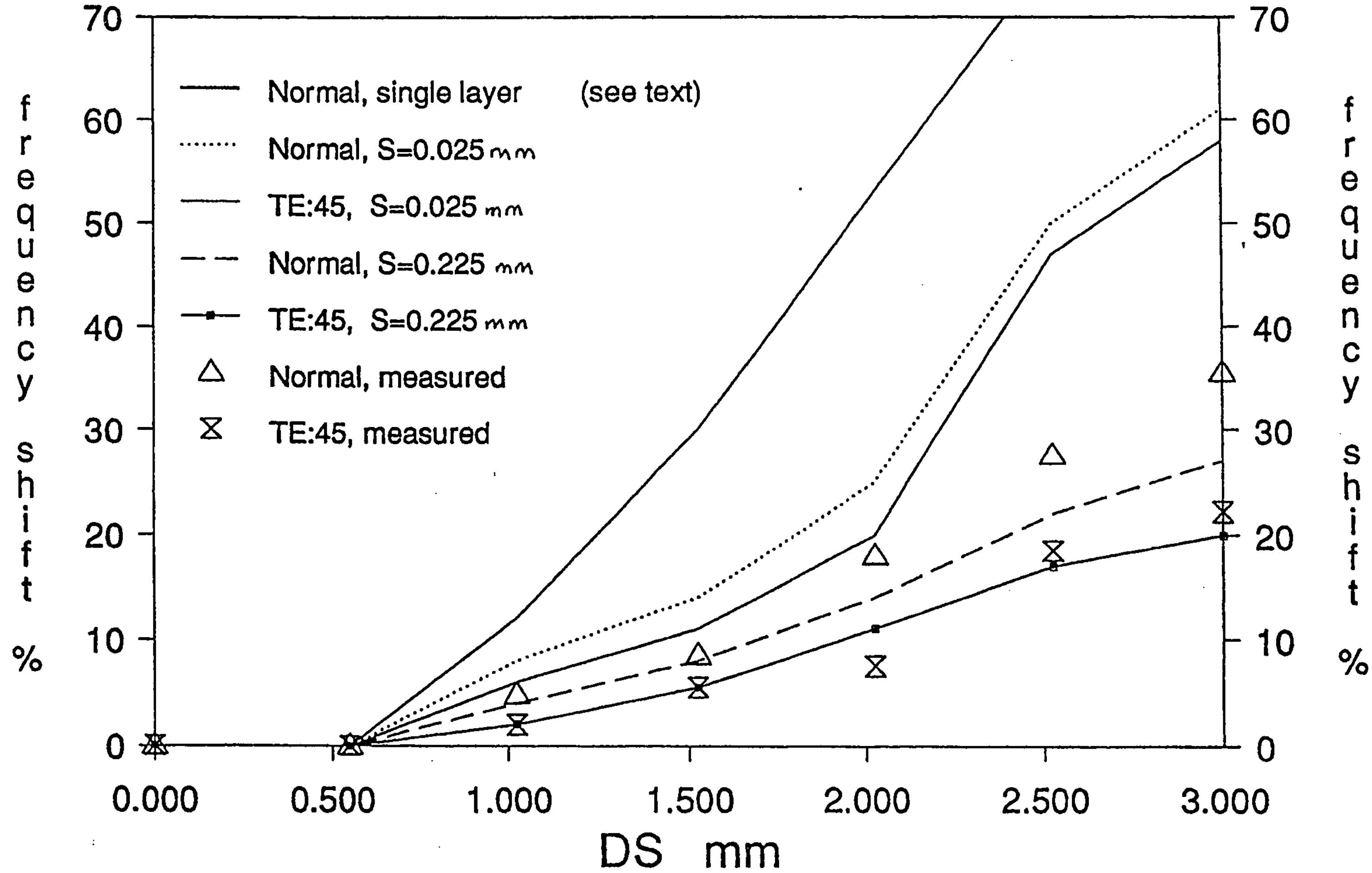


Fig. 4



frequency shift %
70
60
50
40
30
20
10
0
Normal, single layer (see text)
Normal, S=0.025 mm
TE:45, S=0.025 mm
Normal, S=0.225 mm
TE:45, S=0.225 mm
Normal, measured
TE:45, measured
0.000
0.500
1.000
1.500
2.000
2.500
3.000
DS mm

Fig. 5

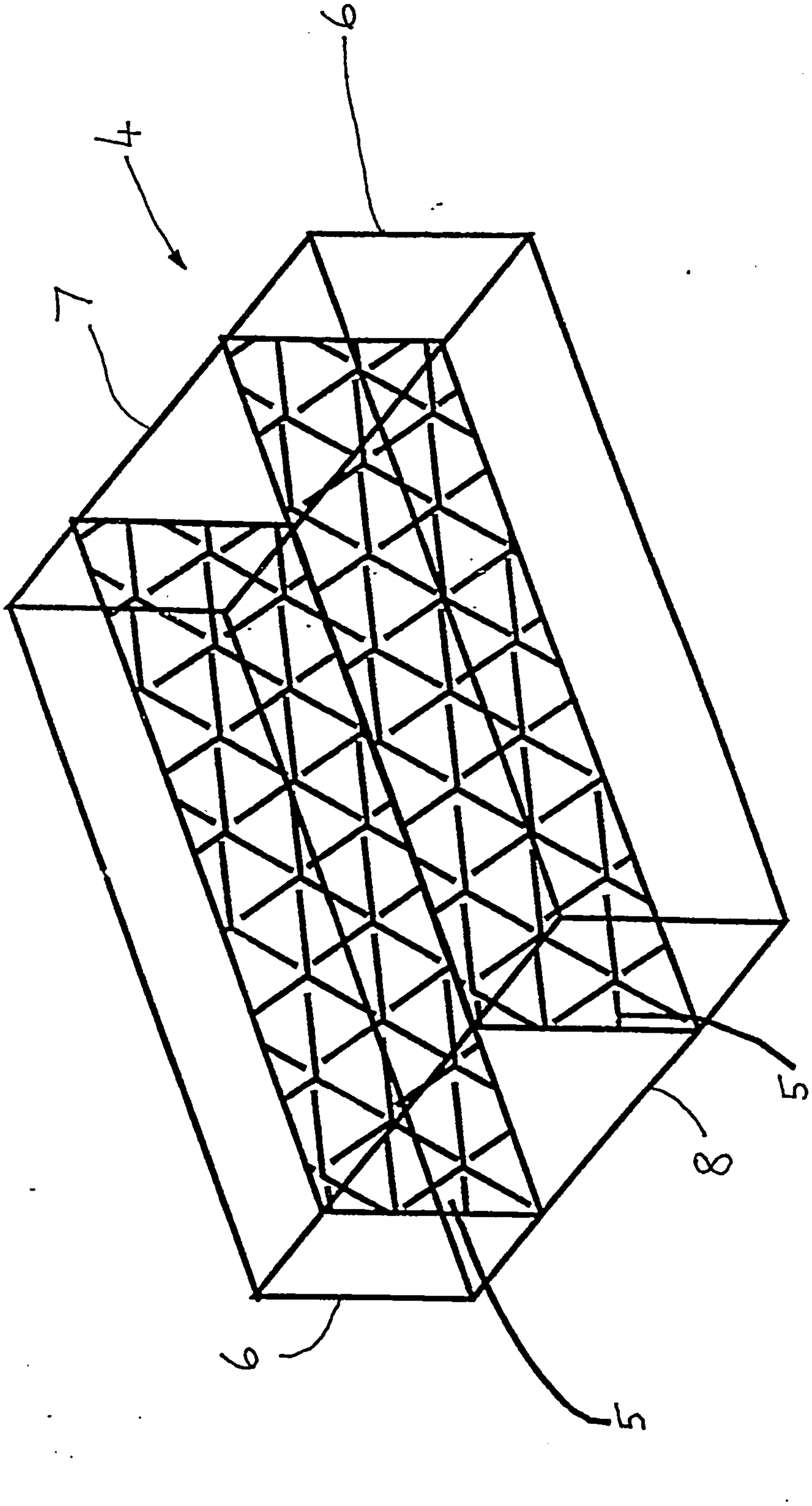


Fig. 6

Reconfigurable frequency selective surfaces

The present invention relates to a reconfigurable frequency selective surface and a method of reconfiguring the frequency response of a frequency selective surface. The present invention also relates to a waveguide including a frequency selective surface.

A frequency selective surface (FSS) is an array of antenna elements that acts as a passive electromagnetic filter. The surface may comprise an array of electrically conductive elements on a dielectric substrate or, alternatively, a plurality of apertures in a conductive surface. Electromagnetic waves incident on a surface comprising an array of conductive elements are reflected from the surface only in a narrow band of frequencies and are transmitted at other frequencies. With an array of apertures, electromagnetic waves are transmitted only in a narrow band of frequencies. Such surfaces can be used as multiplexers or radomes in communications systems and can operate at microwave frequencies, including mm-waves, up to infrared and optical frequencies.

Conventional frequency selective surfaces are designed to operate in a particular frequency range, which is determined by the size and the arrangement of the antenna elements and the size of the array. The operating frequency of a particular surface cannot be changed and therefore, when it is necessary to change the frequency of operation, the original surface has to

be replaced with another having a different frequency response. This is undesirable in practice since the surface is generally permanently mounted in an antenna installation and must be accurately aligned. Further, when a single array of very long dipoles is used, an inductive effect is introduced due to the relative proximity of the ends of adjacent dipoles, which destroys the resonance.

According to the present invention, there is provided a reconfigurable frequency selective surface comprising at least two arrays of elements, the arrays being arranged in close proximity with one another so that elements of a first array are closely coupled with elements of a second array adjacent to the first array, the first array being displaceable with respect to the second array to adjust the frequency response of the surface.

The frequency selective surface allows the frequency response of an antenna installation to be reconfigured without having to replace one surface with another. The inductive effect, found with single arrays, does not occur, and there is no major deterioration in the band widths or band spacing ratio as the displacement increases. The response of the reconfigurable surface is therefore stable throughout the frequency range.

The first and second arrays may be substantially parallel with one another.

The array elements may be conductive elements on a

dielectric substrate, or apertures in a conductive substrate, or a combination of the above.

The first and second arrays may have a separation of no more than 0.03 wavelengths, and preferably no more than 0.003 wavelengths of the electromagnetic waves having the resonant frequency of the surface. For example, when microwaves of frequency 30GHz are to be reflected, the separation is advantageously no more than 0.225mm and preferably no more than 0.025mm.

The first array may be displaceable relative to the second array in a direction parallel to the surfaces of the arrays. Alternatively, the frequency selective surface may be reconfigured by rotating the first array with respect to the second array, or by altering the distance and/or the medium separating the first array from the second array. Using that configuration, there is no limit to the distance separating the arrays.

The array elements may be parallel linear dipoles, and the at least one array may be displaceable in the longitudinal direction of the linear dipoles.

According to the present invention there is further provided a method of reconfiguring a frequency selective surface comprising at least two arrays of elements arranged in close proximity with one another so that the elements of a first array are closely-coupled with elements of a second array adjacent to the first array, wherein the first array is displaced with respect to the second array to adjust the frequency response of the

surface.

According to the present invention there is further provided a method of reconfiguring a beam associated with a grating lobe, wherein the periodicity of a reconfigurable frequency selective surface as described above is adjusted by altering the relative positions of the first and second arrays of the frequency selective surface.

The present invention further provides a waveguide including a frequency selective surface, the frequency selective surface being arranged to influence the frequency response of the waveguide.

A frequency selective surface may be provided over an open end of the waveguide.

At least one frequency selective surface may be mounted within the waveguide, parallel to a wall thereof. Two frequency selective surfaces may be mounted within the waveguide, parallel to the side walls thereof.

The frequency selective surface may be a reconfigurable frequency selective surface, as described in any one of the preceding paragraphs.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a perspective view of a frequency selective surface;

Figure 2 is a cross-section through the surface;

Figure 3 is a diagrammatic view of a part of the surface;

Figure 4 shows the frequency response of a frequency selective surface;

Figure 5 shows the variation of the frequency response as the surface is reconfigured, and

Figure 6 shows a waveguide including a frequency selective surface.

As shown in figure 1, the frequency selective surface consists of two parallel arrays 1,2 of elements 3. The array elements 3 may be electrically conductive elements, such as dipoles printed on a dielectric substrate or, alternatively, they may be apertures, such as slots, formed in a conductive surface (Babinet's compliment of the former). The two arrays 1,2 are arranged in close proximity with one another, so that the elements 3 of the first array 1 are closely coupled with the elements of the second array 2. The separation S of the arrays is as small as possible, whilst ensuring that the elements of the first array 1 are electrically insulated from the elements of the second array 2, and will generally be of the order of 0.03 wavelengths or less, although this will depend on the particular array design, and the dielectric constant of the substrate.

The second array 2 is displaceable relative to the first array 1 by a small distance DS. In the embodiment shown in figure 1, the second array 2 can be displaced transversely, parallel to the surfaces of the arrays, in the direction of the Y-axis. Other types of displacement

are, however, possible: for example, the second array 2 could be displaced in the direction of the X-axis or the Z-axis (thereby altering the distance S separating the two arrays) or it could be rotated about the Z-axis, or displaced in any combination of those directions.

When the arrays 1,2 are aligned accurately with one another (so that DS=0), the elements 3 of the first array 1 lie directly over the elements of the second array 2, thereby shadowing the second array 2 from the incident electromagnetic waves. The frequency response of the surface is then similar to that of a single array and, as shown in figure 4, includes a narrow reflection band and upper and lower transmission bands. The letters f_R denote the reflection band centre frequency, which corresponds to the resonant frequency of the surface, and the letters f_T denote the frequency of the lower transmission band. The frequencies f_R and f_T of the reflection and transmission bands are determined by the length of the antenna elements 3 and the size of the array.

As shown in figures 2 and 3, the first array 1 has a plurality of elements 3 of length L1, and the second array 2 has a plurality of elements of length L2. The separation D1,D2 and the arrangement of the elements in each of the arrays is similar, so that when DS=0 the elements of the second array 2 lie in the shadows of the elements of the first array 1.

When, as shown in figure 2, the second array 2 is

displaced transversely in the direction Y by a distance DS, the ends of the elements 3 of the second array 2 then extend by a small distance DL beyond the ends of the elements of the first array 1. Since the elements of the two arrays are closely coupled, this produces an increase in the overall effective length of each element, which affects the frequency response of the surface. As shown in figure 5, the reflection frequency f_R of the surface is shifted by an amount that is approximately proportional to the displacement DS. The frequency response of the surface can similarly be translated by displacing the second array 2 in the X or Z directions, by rotating it about the Z-axis, or by any combination of those movements.

An example of the results that can be achieved with a particular reconfigurable frequency selective surface will now be described. The particular frequency selective surface consists of two arrays 1,2 of linear dipoles 3, printed in a square lattice on a 0.037mm thick dielectric substrate of dielectric constant 3. The geometry of the lattice unit cell is shown in figure 3, wherein L represents the length of the antenna element, W the element's width, and D the side length of the unit cell (equal to the separation of adjacent antenna elements). In the first array 1, L=4.3mm, W=0.4mm and D=6mm. In the second array 2, L=3.25mm, W=0.4mm and D=6mm. Each array is square, having sides of length 20cm, and the separation S between the arrays is about

0.225mm.

The measured and theoretical response of the surface to microwaves of frequency 12-40GHz at both normal incidence and a TE incidence of 45°, with the electric field parallel to the dipoles, is shown in figure 5. By comparison, the variation in the frequency response of a single array with increasing dipole length is shown as a solid line at the top of the graph.

When the two arrays are substantially aligned, with DS in the range 0 to 0.625mm, the frequency response of the surface is similar to that of a single array having the dimensions and lattice arrangement of the first array 1. Resonance takes place at frequencies of about 31GHz and 27GHz for normal and TE:45° states of incidence respectively. A frequency shift takes place as the transverse displacement DS of the second array 2 is increased, maximum measured frequency shifts of 36% and 22% for normal and TE:45° states of incidence respectively being achieved at a displacement of DS=3mm. At that displacement, the elements 3 of the second array 2 completely fill the gaps between the elements of the first array 1, and so a further increase in the displacement DS has no further effect on the frequency response of the surface.

Reducing the separation S of the arrays, thereby increasing the coupling between the elements, allows greater frequency shifts to be achieved. For example, with a separation of 0.025mm, frequency shifts of up to

60% can theoretically be obtained. The theoretical frequency shift at a separation S of 0.025mm is also shown in figure 5. There is no deterioration in the band widths or band spacing ratio (f_R/f_T) of the surface as the displacement increases and the response of the surface is therefore stable throughout the frequency range.

Various modifications of the apparatus described above are, of course, possible. Many different array geometries could be used and each array may consist either of a plurality of conductors on a dielectric substrate, or a perforated plate, or a combination of both. The antenna elements may be dipoles, cross-dipoles, tripoles, Jerusalem crosses, squares, open-ended loops or any other type of antenna element. The elements need not necessarily be arranged periodically and the arrays may be planar or curved. The frequency selective surface may further consist of two or more closely-coupled arrays of elements, and the respective arrays may either be displaced in a direction parallel to the surfaces of the arrays, or rotated or their separation altered, or the medium separating the arrays may be adjusted (for example, by adjusting its dielectric constant).

The relative displacement of the two arrays may be controlled in various different ways. For example, piezoelectric actuators can be used to control the precise relative movement of the arrays, and the arrays

can be printed directly onto the piezoelectric material. The frequency selective surface may have piezoelectric actuators positioned at some sub-areas of its surface, i.e. not everywhere on its surface. Such an arrangement could, for example, be used to align a FSS on a satellite. Alternatively, the arrays can be mounted at a small separation and air pumped from the gap between the arrays to alter their separation.

Another application of the reconfigurable frequency selective surface is to reconfigure the beam associated with grating lobes. Grating lobes are radiated by the frequency selective surface when the wavelength at which the surface is operating is approximately equal to or smaller than the separation of the elements in the surface (the periodicity of the surface). The spatial position of the grating lobes depends in part on the periodicity of the surface, and since the periodicity can be adjusted by moving one of the arrays relative to the other one, the direction of the beam associated with those lobes can be adjusted simply by altering the relative positions of the arrays. The operating frequency can be kept fixed, and the transmitted or reflected beam can be scanned over a range or adjusted according to the changes in the periodicity, thereby providing a periodicity scan array.

A further application of a frequency selective surface is as a filter in a waveguide. Locating a FSS over the open end of a waveguide enables the frequency of

the electromagnetic waves entering the waveguide to be selected and, if a reconfigurable FSS is used, that frequency can be varied.

Alternatively, the operating frequency range of the waveguide may be extended by mounting one or more frequency selective surfaces inside the waveguide, parallel to one or more of its walls, and dividing the waveguide longitudinally into two or more portions. For example, as shown in figure 6, the waveguide 4 may include two frequency selective surfaces 5, mounted parallel to its two side walls 6. The frequency selective surfaces 5 can be arranged to transmit at low frequencies and to reflect at higher frequencies. The surfaces 5 will then be invisible to the electromagnetic waves in the lower frequency band, and the effective internal dimensions of the waveguide 4 will be defined by the side walls 6 and the upper and lower walls 7, 8 of the waveguide 4. At higher frequencies, the frequency selective surfaces 5 will reflect the electromagnetic waves, and the effective internal dimensions of the waveguide 4 will then be defined by the surfaces 5 and the upper and lower walls 7, 8 of the waveguide. The effective dimensions of the waveguide will therefore be different for different frequencies of transmitted electromagnetic wave, so increasing the operating frequency range of the waveguide. Use of a reconfigurable frequency selective surface permits even finer control of the waveguide operating frequency.

Claims:

1. A reconfigurable frequency selective surface comprising at least two arrays of elements, the arrays being arranged in close proximity with one another so that elements of a first array are closely coupled with elements of a second array adjacent to the first array, the first array being displaceable with respect to the second array to adjust the frequency response of the surface.

2. A surface as claimed in claim 1, in which the first and second arrays are substantially parallel with one another.

3. A surface according to claim 1 or claim 2, in which the elements are conductive elements on a dielectric substrate.

4. A surface according to claim 1 or claim 2, in which the elements are apertures in a conductive substrate.

5. A surface according to any one of the preceding claims, in which the first and second arrays have a separation of no more than 0.03 wavelengths of the electromagnetic waves having the resonant frequency of the surface.

6. A surface according to claim 5, in which the first and second arrays have a separation of no more than 0.003 wavelengths of the electromagnetic waves having the resonant frequency of the surface.

7. A surface according to any one of the preceding claims, in which the first array is displaceable relative to the second array in a direction parallel to the surfaces of the arrays.

8. A surface according to any one of the preceding claims, in which the separation of the first array with respect to the second array is adjustable.

9. A surface according to any one of the preceding claims, in which the medium separating the arrays is adjustable.

10. A surface according to any one of the preceding claims, in which the first array is rotatable with respect to the second array.

11. A surface according to any one of the preceding claims, in which the elements are parallel linear dipoles.

12. A surface according to claim 11, in which the first array is displaceable with respect to the second array in

the longitudinal direction of the linear dipoles.

13. A reconfigurable frequency selective surface substantially as described herein with reference to, and as illustrated by, the accompanying drawings.

14. A method of reconfiguring a frequency selective surface comprising at least two arrays of elements arranged in close proximity with one another so that the elements of a first array are closely-coupled with elements of a second array adjacent to the first array, wherein the first array is displaced with respect to the second array to adjust the frequency response of the surface.

15. A method according to claim 14, in which the first array is displaced relative to the second array in a direction parallel to the surfaces of the arrays.

16. A method according to claim 14 or claim 15, in which the separation of the first array with respect to the second array is adjusted.

17. A method according to any one of claims 14 to 16, in which the medium separating the arrays is adjusted.

18. A method according to any one of claims 14 to 17, in which the first array is rotated with respect to the

second array.

19. A method according to any one of claims 14 to 18, in which the array elements are parallel linear dipoles and the first array is displaced in the longitudinal direction of the linear dipoles.

20. A method of reconfiguring a frequency selective surface, the method being substantially as described herein with reference to, and as illustrated by, the accompanying drawings.

21. A method of reconfiguring a beam associated with a grating lobe, wherein the periodicity of a reconfigurable frequency selective surface according to any one of claims 1 to 13 is adjusted by altering the relative positions of the first and second arrays of the frequency selective surface.

22. A waveguide including a frequency selective surface, the frequency selective surface being arranged to influence the frequency response of the waveguide.

23. A waveguide according to claim 22, in which a frequency selective surface is provided over an open end of the waveguide.

24. A waveguide according to claim 22 or claim 23, in

which at least one frequency selective surface is mounted within the waveguide, parallel to a wall thereof.

25. A waveguide according to claim 24, in which two frequency selective surfaces are mounted within the waveguide, parallel to the side walls thereof.

26. A waveguide according to any one of claims 22 to 25, in which the frequency selective surface is a reconfigurable frequency selective surface, according to any one of claims 1 to 13.

27. A waveguide substantially as described herein with reference to, and as illustrated by, Fig. 6 of the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number 9119039.7

Relevant Technical fields	Search Examiner
(i) UK Cl (Edition K) H1Q (QEC, QEJ, QEX, QKJ)	J BETTS
(ii) Int Cl (Edition 5) G01S	
Databases (see over)	Date of Search
(i) UK Patent Office	3 FEBRUARY 1992
(ii) -	

Documents considered relevant following a search in respect of claims 1-21, 26

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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Examiner's report to the Comptroller under Section 17 (The Search Report)

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Relevant Technical fields

(i) UK Cl (Edition K) H1Q (QEC,QEJ,QEX,QKJ)
H1W (WBA,WBX)

(ii) Int CL (Edition 5) H01P,H01Q

Search Examiner
J BETTS

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search
5 MAY 1992

Documents considered relevant following a search in respect of claims 22-25,27

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 1235879 A (McMILLAN) - See figure 3A	22-24

Category	Identity of document and relevant passages	Relevant to claim(s)

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